Fermilab FERMILAB-PUB-04-319-A-CD-E NOVEMBER 2004

Fermi National Accelerator Laboratory
The Fermilab Particle Astrophysics Center
Batavia, IL 60510

The following report covers activities from November 2003 through October 2004.

1 Introduction

The Particle Astrophysics Center was established in fall of 2004. Fermilab director Michael S. Witherell has named Fermilab cosmologist Edward "Rocky" Kolb as its first director. The Center will function as an intellectual focus for particle astrophysics at Fermilab, bringing together the Theoretical and Experimental Astrophysics Groups. It also encompasses existing astrophysics projects, including the Sloan Digital Sky Survey, the Cryogenic Dark Matter Search, and the Pierre Auger Cosmic Ray Observatory, as well as proposed projects, including the SuperNova Acceleration Probe to study dark energy as part of the Joint Dark Energy Mission, and the ground-based Dark Energy Survey aimed at measuring the dark energy equation of state.

1.1 Personnel

Affiliations to group and experiments below are given for each name as follows: Theory group (TAG, §2), Sloan Digital Sky Survey (SDSS, §3), Experimental group (EAG, §4), Pierre Auger Project (Auger, §5), Cryogenic Dark Matter Search (CDMS, §6), SuperNova Acceleration Probe (SNAP, §7), and Dark Energy Survey (DES, §8).

Scientists: Jim Annis (SDSS, EAG, DES) Aaron Chou (Auger), Dan Bauer (CDMS), Mike Crisler (CDMS), Fritz DeJongh (SDSS, SNAP), Roger Dixon (CDMS), Scott Dodelson (SDSS, TAG (head), SNAP, DES), Juan Estrada (DES), Brenna Flaugher (DES), Josh Frieman (SDSS, TAG, SNAP, DES), Henry Glass (Auger), Carlos Hojvat (Auger), Don Holmgren (CDMS), Lam Hui (SDSS, TAG), Stephen Kent (SDSS, EAG (head), SNAP (head), DES), Rocky Kolb (SDSS, TAG, director of Center for Particle Astrophysics), Richard Kron (SDSS (director), EAG (associate head)), Peter Limon (SNAP, DES), Huan Lin (SDSS, EAG, SNAP, DES), Matthew Malek (Auger), Paul Mantsch (Auger), John Marriner (SDSS), Peter Mazur (Auger), Cathy Newman-Holmes (Auger), John Peoples (SDSS, DES), Erik Ramberg (CDMS), Vic Scarpine (DES), Albert Stebbins (SDSS, TAG (deputy head)), Chris Stoughton (SDSS, EAG (deputy head)), SNAP, DES), Douglas Tucker (SDSS, EAG, SNAP, DES), Louis Voyvodic (Auger), Jochen Weller (TAG), William Wester (DES), Brian Yanny (SDSS, EAG)

Postdocs: Gianfranco Bertone (TAG), Mark Jackson (TAG), Sebastian Jester (SDSS, EAG), Kenji Kadota (TAG), Hubert Lampeitl (SDSS, EAG), Jonghee Yoo (CDMS), Pengjie Zhang (TAG)

Short-term Visitors: Sahar Allam (NMSU), Chatief Kunjaya (Bandung), David Moore (Yale), Cristin Rider (Boston University/JHU)

2 Theoretical Astrophysics Group

The Theoretical Astrophysics Group works on a broad range of topics ranging from string theory to data analysis in the Sloan Digital Sky Survey. The group is motivated by the belief that a deep understanding of fundamental physics is necessary to explain a wide variety of phenomena in the universe. In the previous year, the Theoretical Astrophysics Group authored or co-authored fifty papers, highlights of which appear below.

2.1 Theoretical Cosmology and the Early Universe

Jackson and collaborators studied the role that string windings may have played in the early universe, finding that the winding modes oppose cosmological growth of particular dimensions. This may explain why our universe appears to be 3+1-dimensional.

Kolb and collaborators have been investigating second order perturbations: their evolution and the way they might be detected. In a series of papers, they argue that, while sub-horizon perturbations are potentially measurable, the most intriguing result is that super-horizon modes potentially contribute an enormous amount to the energy density in the universe. Whether this new form of energy is related to other recently discovered super-horizon anomalies (dark energy and suppression of large angle CMB anisotropies) remains an important area of investigation.

2.2 Phenomenological Cosmology

2.2.1 Weak Lensing and Dark Energy

In work done by Zhang, Stebbins and Hui, it was pointed out that it is possible to extract purely geometrical information from weak lensing surveys. This enables interesting constraints to be put on dark energy that are completely independent of assumptions about structure formation and growth.

Dodelson studied the lensing of the cosmic microwave background (CMB) by galaxy clusters. With high enough resolution, mass estimates can be obtained for large clusters, thereby helping to constrain dark energy. He also studied how accurately weak lensing of background galaxies will enable us to determine cluster masses. By focusing on the problem of projection effects, he proposed a new mass estimator designed to minimize the noise due to structure along the line of sight. Dodelson, Frieman, and student Rozo studied cosmological constraints from clusters using the halo model.

Frieman and collaborators have been studying the prospects of probing dark energy using weak lensing in the Dark Energy Survey (DES), which is described in detail in §8. Lidz, Hui, Crotts, and Zaldarriaga derived the first constraints on dark energy from pairs of quasar spectra.

2.2.2 Sunyaev-Zel'dovich Effect

The Sunyaev Zel'dovich (SZ) effect is entering the era of precision measurement. In the past year, Zhang has been working on the precision modeling of the SZ effect and has made a number of advances. He has developed a precise model of the kinetic SZ effect power spectrum for a uniformly reionized universe. This model has passed the test of a series of hydro simulations and was shown to be free of simulation artifacts. He also showed that the kinetic SZ power spectrum has a strong dependence on the reionization history and therefore will place strong constrains on reionization scenarios.

The thermal SZ effect probes the intergalactic medium (IGM) density and temperature distribution. Zhang and collaborators have run a series of high resolution hydro simulations and given a detailed description of the state of the IGM. They have provided a precise model of the gas mass weighted temperature for adiabatically evolving universe. They then applied this model to predict the mean Compton y parameter of the universe. Gas physics affects the thermal SZ effect. Zhang estimated the effect of a cluster magnetic field and found it can decrease the SZ power spectrum by $\sim 10\%$ at arcminute scales.

The cluster kinetic SZ effect provides a unique measure of the peculiar velocity. But proposed methods to measure the peculiar velocity using the kinetic SZ effects rely on many extra measurements and assumptions, which introduce large systematic errors. Zhang, Stebbins, and collaborators introduced a method of extracting the peculiar velocity power spectrum from the cluster kinetic SZ flux. This method is almost free of systematic errors and the statistical errors can be as small as $\sim 10\%$ for upcoming SZ experiments.

2.2.3 Reionization

Hui, in work done with Haiman, pointed out that existing measurements of the intergalactic medium temperature at redshifts 2 - 4 suggest that a reionization event, involving HI, HeI and/or HeII, must have happened below redshift 10. In conjunction with CMB measurements by WMAP, this implies that our reionization history is likely complex.

2.2.4 Galaxy Distribution

In the SDSS, J. Frieman continues to serve as co-Chair of the Large-scale Structure Working Group. Recent research results in this area which he has been involved in include an analysis of galaxy clustering as a function of luminosity and color and its interpretation in terms of the halo occupation distribution model of bias (with I. Zehavi and collaborators), deriving joint constraints on cosmological and halo bias parameters from this clustering (with K. Abazajian and collaborators), measurement of the galaxy-mass correlation function and its comparison with the galaxy auto-correlation function to constrain bias and the cosmic mass density (with E. Sheldon and collaborators), and use of the SDSS early-type galaxy velocity distribution function to constrain cosmology with strong lensing statistics (with J. Mitchell and collaborators).

Abazajian and Dodelson played key roles in the paper released by SDSS estimating cosmological parameters. They ran Monte Carlo Markov Chains obtaining errors on all cosmological parameters from a joint consideration of WMAP and SDSS. They also explored the systematic uncertainty introduced by nonlinearities in the power spectrum, and showed that this uncertainty does not unduly bias the results.

2.3 High Energy Astrophysics

The flux spectrum is the most widely used statistics of the cosmic MeV gamma-ray background. But the origin of this background is still uncertain and some sources can produce degenerate flux spectra. For the first time, Zhang and Beacom calculated the angular correlation function of this background and its correlation with galaxies. They estimated that these statistics can be measured and applied to disentangle various sources.

Baltz and Hui pointed out that double magnification bias may play a role in determining the microlensing rate of gamma-ray bursts.

Bertone and collaborators concluded a study of a new astrophysical scenario for the origin of the Galactic positron population, invoking Gamma-ray bursts. They also considered quasar remnants as possible sources of ultra high energy cosmic rays.

Beacom and Bell have written a number of papers exploring the astrophysical implications of unstable neutrinos. Beacom, with Vagins, proposed a simple addition to proposed Large Water Cerenkov detectors which would greatly enhance the detectability of cosmic antineutrinos. This upgrade, which is currently being explored by Super-Kamiokande will likely lead to the first detection of the diffuse neutrino background produced by supernovae.

2.4 Dark Matter

Bertone and collaborators published a long review on dark matter this year. They also focused on a number of possible indirect detection mechanisms:

- the study of the internal bremsstrahlung emission associated with the annihilation of MeV Dark Matter particles into positrons, which provides a severe constraint on the mass of light DM candidates
- the study of indirect dark matter detection in the framework of heterotic orbifold models
- the determination of an upper limit on the neutrino

flux expected from Dark Matter annihilation at the galactic center

Beacom, Bell, and Dodelson proposed a mechanism for evading cosmological constraints on neutrino mass. They pointed out that interactions keeping neutrinos in equilibrium would exponentially reduce their numbers in the early universe. If no cosmological neutrinos remain today, then the cosmological limits (from large scale structure) no longer apply.

2.5 Workshops and Conferences

The group organized and hosted a number of conferences and workshops over the past year

- *de Sitter Days*, at Fermilab in November, 2003
- *Santa Fe Cosmology Workshop*, now a yearly event designed for maximal interaction of students with senior researchers
- *Ground-based Supernova Surveys*, held in Chicago in November, 2003
- *Large-scale Structure Workshop*, held at the Aspen Center for Physics in January 2004
- *From Zero to Z0: A Workshop on Precision Electroweak Physics*, at Fermilab in May, 2004
- *Dark Energy Workshop*, held in Aspen Center for Physics in August, 2004
- *Fundamental Physics from Clusters of Galaxies*, to be held at Fermilab in December 2004

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3 Sloan Digital Sky Survey

3.1 Survey operations

Members of the Experimental Astrophysics Group perform the survey operations from planning through data reduction, data distribution, and operation of an email helpdesk. This year saw two data releases: DR2 in the spring of 2004, which included a complete reprocessing of DR1 with improved software and calibrations, and DR3 in the fall of 2004, which increased the published sky coverage by 50% to 5282 square degrees of 5-color optical imaging and 4188 square degrees covered by the spectroscopic survey of galaxies, quasars and stars. Survey observing continues with 8216 square degrees of imaging (97% of the total) and 5300 square degrees of spectroscopy (62%) having been completed to date. SDSS data are available via http://www.sdss.org

3.2 Advanced data products

H. Lin, in collaboration with H. Lampeitl, J. Annis, V. Sekhri, and N. Sharma, has worked on generating coadded images using the repeat imaging runs on the SDSS southern equatorial stripe, and on producing SExtractor photometric catalogs for the coadded data. Two sets of coadds have been made: a PSF-optimized coadd using the best-seeing half of the input data has been produced using Fermilab's qcdhome computer cluster, and a full-depth coadd using all input data has been produced using Grid3 computing resources. These deeper coadd images have been used for strong lensing arc searches and will be used for cluster finding, weak lensing, and other projects.

3.3 SDSS II

Members of the EAG, (including Brian Yanny, C. Stoughton, J. Adelman, J. Hendry, D. Tucker, S. Kent, J. Inkmann, D. Yocum and H. Lin) are actively participating in planning and testing operations of a proposed extension to SDSS, designated SDSS-II, which is composed of three interrelated projects, including:

3.3.1 SDSS Legacy

A legacy program to 'fill the gap' by obtaining quasar and galaxy spectra over an area of about 1800 square degrees of sky near the North Galactic pole will help map the largest contiguous area of sky ever obtained at SDSS precision and depth.

3.3.2 SEGUE

The Sloan Extension for Galactic Underpinnings and Evolution (SEGUE) program plans to obtain approximately 3600 square degrees of imaging at low Galactic latitude $|b| < 30$ degrees and $R \sim 1800$, $S/N > 15$ spectra of approx. 240,000 Milky Way stars, carefully selected from a variety of sight-lines and spectral types. The SEGUE project aims to produce a next-generation structural and kinematic model of the Galaxy and its near neighborhood.

3.3.3 Supernova Survey

Members of the Theoretical and Experimental Astrophysics groups (including J. Adelman, J. Frieman, F. DeJongh, J. Marriner, H. Lampeitl, and C. Stoughton and collaborators) are laying the foundations for a Supernova Survey in SDSS II, with the aim of obtaining densely sampled, multi-band light-curves for 200 Type Ia supernovae in the redshift range z=0.1-0.35 to probe the Dark Energy. In Fall 2004, they are carrying out a pilot survey using 20 nights of scheduled, repeat imaging on the SDSS 2.5m telescope, with spectroscopic follow-up on the ARC 3.5m, HET, and possibly other telescopes. They are also part of a group identifying supernovae in near-real time from SDSS galaxy spectra.

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4 Experimental Astrophysics Group

4.1 Stellar and Galactic Astronomy

4.1.1 Southern $u'g'r'i'z'$ Standard Stars

Douglas Tucker has been working on a project, led by J. Allyn Smith of LANL, to extend the $u'g'r'i'z'$ standard star system to the Southern Hemisphere.[1] The observations for this project, which were recently completed, were obtained over the past four years on the CTIO 1.0m telescope. Analysis of the dataset is underway (Stute et al., in preparation; Smith et al., in preparation).

4.1.2 Open Clusters

Douglas Tucker and J. Allyn Smith (LANL) have been using $u'g'r'i'z'$ photometry of open clusters as the basis for summer projects for undergraduate interns the past two years. The open clusters studied so far include NGC 2548 (M48) (Rider et al. 2004), Hogg 19 (Moore et al., in preparation), and NGC 1647 (Cantrell et al., in preparation).

4.1.3 Milky Way Streams and Structure

Brian Yanny and Steve Kent are actively pursing exploration of the structure and dynamics of the Milky Way as told by the positions, number counts and kinematics of Galactic stars as observed by SDSS. The nature of the low-latitude stream around the Galaxy continues to be an area of active research (Beers et al. 2004) and the extent of the Sagittarius stream stars (Newberg et al. 2003) continues to push model builders towards ever more complex models of the potential and component structure of our Galaxy. The proposed SEGUE project (see 3.3.2 above) will add greatly to the database available for this research in the upcoming period.

4.2 Extragalactic Astronomy

4.2.1 Properties of galaxies

In conjunction with Sahar Allam (NMSU), Brian Lee (LBNL), and J. Allyn Smith (LANL), Douglas Tucker studied the properties of SDSS galaxies in extreme environments: merging pairs of galaxies (Allam et al. 2004), compact groups of galaxies (Lee et al. 2004), and isolated galaxies (Allam et al., in press).

4.2.2 SDSS Galaxy redshift survey

H. Lin has worked on deriving survey completeness, redshift success rates, and luminosity functions using the Low-z and other Southern Survey spectroscopic samples, which extend down to $r \approx 19.5$, or about 2 magnitudes fainter than the SDSS main galaxy sample. Preliminary results were presented at the Spring 2004 SDSS collaboration meeting and a paper is in preparation on the evolution of the galaxy luminosity function at $z \lesssim 0.2$.

4.2.3 Photometric redshifts

H. Lin, in collaboration with P. Hsieh (ASIAA) and H. Yee (Toronto), has worked on deriving photometric redshifts for 30 square degrees of *BVRz* mosaic CCD imaging data in the Red-Sequence Cluster Survey (RCS) and CNOC2 Redshift Survey fields, using a polynomial fitting technique and spectroscopic redshift calibrators from the CNOC2 and Hawaii HDF-North data sets. Photometric redshift catalogs have been made available to the RCS/CNOC2 collaborators and a paper is in preparation.

4.2.4 Strongly lensed arcs in SDSS coadd data

H. Lin, in collaboration with H. Lampeitl, J. Annis, and J. Frieman, has been carrying out a program to search for strong lensing arc systems in the SDSS southern coadd data. Our best candidate has been shown to be a very likely strong lensing system, given deeper Magellan imaging and spectroscopy from M. Gladders (Carnegie) and deeper WIYN imaging from J. Hennawi (Berkeley) et al. Several additional promising candidate systems have also been found, including another very likely system with followup imaging obtained on the APO 3.5m telescope.

4.2.5 Spectral-line fitting for quasars

C. Stoughton and S. Jester, in collaboration with D. Vanden Berk (Penn State), have developed a genetic algorithm for fitting UV/optical quasar spectra in detail. The continuum, emission line, and host galaxy components are fit simultaneously. The continuum is modeled with a power law and Balmer continuum. Major emission lines are modeled with one to three Gaussians per line. Iron emission complexes are modeled with multiple Gaussians, based on narrow-lined Seyfert spectra and theoretical line models. The host galaxy component is modeled using galaxy eigenvectors. A typical SDSS quasar spectrum is modeled using over 150 parameters. The fitting routine uses a "genetic" algorithm to search the parameter space to minimize the Chi-squared value of the model fit to the spectroscopic data. The algorithm requires a minimum of human supervision, and returns stable, robust results. The algorithm has been run on over 16,000 SDSS Data Release One spectra using computer clusters at Fermilab and the TeraGrid cluster at

[1] http://home.fnal.gov/~dtucker/Southern_ugriz

NCSA. Results will be used for a range of studies of the emission line properties of quasars.

4.2.6 The SDSS View of the Completeness of the PG Bright Quasar Survey

S. Jester is leading an investigation of the Palomar-Green Bright Quasar Survey completeness using SDSS data. Objects from the BQS have served as sample cases for the study of the quasar population as a whole using every new space telescope. However, it has remained unclear whether the BQS substantially underestimates the surface density of bright quasars, and whether there are any systematics to the incompleteness. No statistically significant differences are found in the distributions of optical colors, redshift, or radio properties taken from the FIRST survey (radio flux, power, and radio-optical flux ratio). Thus, PG quasars constitute a representative sample of quasars which are bright in the B-band. However, the i-band limited SDSS sample includes objects with a much wider range of colors at i-band magnitudes similar to those of the PG objects. A paper is in preparation (with Richard Green, NOAO, James Gunn, Gordon Richards, Michael Strauss, Princeton, Maarten Schmidt, Caltech, Don Schneider, Penn State, and the SDSS collaboration).

4.2.7 AGN jets

S. Jester has been continuing a study of the synchrotron emission from the jet in 3C 273 with the Very Large Array and the Hubble Space Telescope to investigate the multiple synchrotron emission components of the jet, yielding observational constraints on particle acceleration mechanisms which must be acting in this and similar jets (Jester et al., A&A accepted; with Hermann-Josef Röser and Klaus Meisenheimer, Heidelberg, and Rick Perley, NRAO Socorro).

It is currently unclear whether the X-ray emission process in this jet is synchrotron or beamed inverse-Compton emission off the microwave background. To shed light on this issue, the Chandra X-ray Observatory was used to monitor the jet's X-ray emission for time variability, which would argue for synchrotron emission. These data are currently being analyzed (with Dan Harris, CfA, and Herman Marshall, MIT).

S. Jester is also interested in analogies between accretion processes in galactic black hole X-ray binaries and active galactic nuclei (ApJ, submitted) and tests of the apparent dichotomy of the radio properties of optically selected quasars (Jester & Kron 2004).

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5 The Pierre Auger Project — A Study of the Highest-Energy Cosmic Rays

Over the past thirty years cosmic ray air shower detectors have recorded a number of events with energies near or above 10^{20} eV. These super-high-energy events are extraordinary for two reasons. First, there are no known acceleration mechanisms that can produce particles of these energies. Second, the attenuation length for cosmic rays with energy greater than 1.5×10^{19} eV is less than about 30 Mpc. This attenuation (known as the Greisen-Zatsepin-Kuzmin cutoff) results from the interaction of cosmic ray particles with the cosmic microwave background. Thus particles of these energies can only reach the earth if they are produced relatively nearby. The high magnetic rigidity of these particles also means that they suffer little deflection from galactic and extragalactic magnetic fields and should point to their sources. Yet none of the particles observed points back to a possible astrophysical source within the distance limit imposed by the background radiation.

The Pierre Auger Project is a broadly-based international effort by 15 countries to make a high statistics, full sky study of cosmic rays at the highest energies. Two air shower detectors will be built, one to be placed in the Northern Hemisphere and one in the Southern Hemisphere. Each installation will consist of an array of 1600 particle detectors spread over 3000 km^2. Each installation will also have 24 atmospheric fluorescence telescopes viewing the cascade in the volume above the surface array. These two complementary air shower detector techniques working together form a powerful instrument for this research.

Construction of the southern site of the Auger Observatory was started in Mendoza, Argentina with an engineering array at the beginning of 2000. The Engineering Array, consisting of 30 surface detectors and two prototype fluorescence telescopes, demonstrated that the detectors perform very well, indeed better than expected. It now appears likely we will be able to reconstruct air showers at zenith angles almost to the horizon. This enhanced aperture extends the physics possibilities to include neutrinos and other exotics that come from near the horizon.

Observatory components are now in full production and are being deployed as they reach the site. More than 500 surface detector stations and 12 (half) of the fluorescence telescopes are operational. The large data set already accumulated includes more than 1000 hybrid events, those in which the air shower is viewed by the surface array and one or more of the fluorescence telescopes. The Auger surface array is now the largest in the world. Completion is expected by the end of 2005 or early 2006.

6 Cryogenic Dark Matter Search (CDMS)

Observations of galaxies, superclusters, distant supernovae and the cosmic microwave background radiation, tell us that ~85% of the matter in the universe is not made of ordinary particles. Deciphering the nature of this dark matter would be of fundamental importance to cosmology, astrophysics, high-energy particle physics and our understanding of gravity. A leading hypothesis is that it is comprised of Weakly Interacting Massive Particles, or WIMPs, that were produced moments after the Big Bang. If WIMPs are the dark matter, then their presence in our Milky Way may be detectable via scattering from atomic nuclei in a terrestrial detector.

The Cryogenic Dark Matter Search (CDMS) Collaboration, supported jointly by NSF and DOE, has pioneered the use of low temperature phonon-mediated detectors to distinguish the rare scattering of WIMPs on nuclei from prominent radioactive backgrounds. We developed this powerful technology at a shallow site, the Stanford Underground Facility, and are now operating deep underground in the Soudan mine in Minnesota. Within the next few years, we plan to mount a larger version of the experiment at an even deeper facility; SNOLAB in Sudbury, Ontario, Canada.

6.1 CDMS at Soudan

The CDMS experimental apparatus consists of very pure Ge (250 g) and Si (100 g) crystals cooled to ultralow temperatures (50 mK). The detectors are surrounded by layers of active and passive shielding, to reduce backgrounds from residual cosmic rays and from decay products of trace radioactivity in the surrounding cavern. The detectors use simultaneous measurement of athermal phonons and ionization to reject background particles that scatter off electrons in the detectors. Since WIMPs scatter off nuclei, this technique preferentially selects WIMP interactions and not those from backgrounds. The only conventional background to escape this 'filter' is neutrons. Since these are primarily generated in cosmic ray interactions, they are the chief reason the experiment is conducted deep underground.

The CDMS experiment at Soudan includes the fabrication, testing and operaton of five towers of detectors, each with six ZIP detectors. Towers 1 & 2 were installed at Soudan in March 2003, and the detectors were cooled to a base operating temperature below 50 mK by June 2003. In the fall of 2003 we began the operation of Tower 1, and in 2004 we operated both Towers 1 & 2.

A blind analysis of the first data set revealed no nuclear-recoil events in 52.6 kg-d raw exposure in our Ge detectors. These data set an upper limit on the WIMP-nucleon cross-section of 4×10^{-43} cm^2 at the 90% C.L. at a WIMP mass of 60 GeV for (spin-independent) coherent scalar interactions and a standard WIMP halo. At 60 GeV, this limit is eight times lower than our previous results and four times lower than that of our nearest competitor. A report on these results has been accepted for publication in *Physical Review Letters* (Akerib et al. 2004) and a detailed *Physical Review* paper is in preparation.

During the second run, from March to August, 2004, an additional exposure of ~ 75 kg-days was taken with both Towers 1 and 2. A factor of 3 improvement in sensitivity is to be expected from the combined data set once the analysis is completed (expected by the end of 2004).

We warmed up the experiment in August 2004 (after nearly a year at 50 mK!) and are currently installing several necessary upgrades and three more detector towers. Based on our projected exposure of 1200 kg-d through 2005, we expect to extend our sensitivity for a WIMP-nucleon cross section down to a 90%-C.L. upper limit of $\sim 3 \times 10^{-44}$ cm^2 and a 99%-C.L. detection at $\sim 6 \times 10^{-44}$ cm^2.

6.2 SuperCDMS at SNOLAB

Building on the success of CDMS at Soudan, we are planning an ambitious program that will extend sensitivity to WIMP-nucleon scattering by more than a factor of 100 over the present generation of experiments and by a factor of 1000 over currently published limits. Labeled as SuperCDMS, this experiment will be constructed at the expanded SNOLAB facility in Canada. As currently conceived, it will include three phases: a 25 kg Ge experiment (Phase A), then a 150 kg Ge experiment (Phase B), and eventually a ton scale experiment. This phased approach will allow us to maintain the best discovery potential of any experiment in the world for finding WIMPs. The ultimate reach of the experiment is comparable to that of the LHC for supersymmetric neutralinos, one of the best WIMP candidates.

PUBLICATIONS

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7 SuperNova Acceleration Probe (SNAP)

Sixteen Fermilab scientists have recently joined the SNAP project, which is being led by the Lawrence Berkeley National Laboratory. SNAP is a proposed space-based experiment to measure the equation of state of dark energy by observing supernovae at high redshift and utilizing their predictable absolute luminosity as a standard candle to measure the expansion history of the universe. In addition, SNAP will measure weak lensing of distant galaxies as another technique to probe dark energy. SNAP will be proposed as the dark energy experiment on the NASA/DOE Joint Dark Energy Mission (JDEM). As part of the planning activities for SNAP, Fermi scientists are working on identifying standard stars for accurate spectrophotometric calibrations, simulating the weak lensing experiment, developing a software environment for making simulated data, testing the radiation hardness of mass memory devices and memory control electronics, and evaluating the effectiveness of radiation shields.

H. Lin has worked on producing galaxy luminosity-redshift distributions and photometric redshift simulations for the SNAP weak lensing simulation effort. Results have been presented at SNAP collaboration meetings. H. Lin has also carried out tests of lossy image compression via square-root prescaling, indicating promise for use in the SNAP Wide Area Survey; a report co-authored with J. Marriner was presented to the SNAP collaboration in January 2004.

Douglas Tucker has been active in the SNAP Calibration Working Group. He, Steve Kent, and Sahar Allam (NMSU) have been leading an effort to identify faint (V=15-19) candidate spectrophotometric standards in and near the SNAP North supernova field, a 7.5 sq deg field centered at RA=245.25deg, DEC=+55.58deg (J2000).

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8 The Dark Energy Survey (DES)

The Dark Energy Survey is a ground based project aimed at measuring the dark energy equation of state at the 5-15% level with each of 4 independent techniques: cluster counting (in conjunction with the SZ survey of the South Pole Telescope), weak lensing measurements of shear-shear and shear-galaxy signatures, the redshifting of the galaxy angular power spectrum peak, and type Ia supernovae light curves. The primary survey consists of a 5000 sq-degree g,r,i,z survey to i=24 (10σ, galaxy) and a 10% in time supernova survey of 40 sq-degrees. The

DES collaboration consists of 35 scientists from 5 institutions (Fermilab, UIUC, UC, LBNL and CTIO). John Peoples is the Director, Brenna Flaugher the Project Manager, and Jim Annis the Project Scientist, all of Fermilab; Joe Mohr of UIUC leads the DES data management project. During the last year the project was initiated. It has passed the first rounds of community consensus building and project planning. DES received Stage I approval from Fermilab. The collaboration submitted a proposal to NOAO in July 2004, which is available on the project web page http://www.darkenergysurvey.org

The design for the 62 CCD Dark Energy Camera is well developed. We plan to use the full-depletion red sensitive CCDs developed at LBNL. We have entered a partnership with NOAO and its CTIO where in return to community access to the instrument, 30% of the CTIO Blanco 4m time over 5 years (2009-2014), is devoted to the DES. Steve Kent is working on the optics, Chris Stoughton and Huan Lin on simulations, Douglas Tucker is working on the calibrations, William Wester, Juan Estrada and Vic Scarpine are working on front end electronics and CCD testing and Josh Frieman is working on weak lensing systematics as well as photometric redshifts. The Fermilab efforts center on the camera construction, the CCD packaging and testing, the survey strategy and calibration, the coadd and photometric calibration pipelines, and on a full simulation of the survey science and instrument.

H. Lin, in collaboration with J. Frieman and U. Chicago students C. Cunha, M. Lima, and H. Oyaizu, has worked on photometric redshift simulations for field and cluster galaxies for the DES with the aim of quantifying systematic errors and tracing them through to the impact on cosmological parameter determination. Photometric redshift error distributions have been computed as a function of redshift, magnitude, and galaxy type, and different photometric redshift techniques (including template fitting, polynomial fitting, and neural networks) have been compared using both simulated and real data sets. Some results have been described in the DES proposals to Fermilab advisory committees and to NOAO, and a review paper on photometric redshift techniques is in preparation.

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